# 19.—THE GEOLOGY AND PHYSIOGRAPHY OF THE WONGONG-CARDUP AREA

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CONTENTS.

## I. INTRODUCTION.

The Wongong-Cardup area lies about 20 miles south-south-east of Perth. It extends for four and a half miles along the Darling Scarp, which forms the western edge of the Darling Peneplain (Jutson, 1934, p. 84), from Cardup Brook in the south, to half a mile north of Wongong Brook and it covers about six square miles.

The rocks, bounded on the west by the sedimentary Cardup series, consist mainly of granites and gneisses of the Pre-Cambrian Darling Complex (Clarke, 1938, p. 21). These rocks are all intruded by later greenstone dykes. The geology generally is similar to that of the Armadale area (Prider, 1941). The examination of the area was conducted to determine whether the features of this small closely mapped Armadale area were maintained to the south, and to obtain further data regarding the extent of the Cardup series and its relation to the granitic rocks. Good exposures of the Cardup sediments have been made at Byford and Cardup where the slates are quarried for the manufacture of pressed bricks.

Published information regarding the geology of the area is as follows:—

Honman (1912) traced outcrops of the Cardup sediments at many points along the front of the scarp.

Esson (1922) examined the rocks of the Wongong dam site several miles east of the area, and in 1926 he reported on the silver lead deposit at Mundijong, several miles to the south, where part of the country in the vicinity of the deposit is made up of the Cardup series.

Clarke (1930) mentioned the Cardup series and published a map of Cardup.

Forman (1937, p. xxiv) considered that the Cardup series conformed to the local structure in the gneisses, which he suggested were derived from the sediments by granitisation.

Both Clarke and Forman correlated the Cardup series with the Jimperding series of Yilgarn age, but Prider (1941) at Armadale has advanced strong evidence indicating that the Cardup series is younger than the granite and gneiss.

The structure and relations of the gneisses to the Cardup series in the Wongong-Cardup area confirm the conclusions reached by Prider.

The area was mapped during 1940 by the author working alone. It has been well subdivided by the Lands and Surveys Department, thus enabling detailed mapping to be done by pace and compass traverses. Form lines were drawn from spot heights obtained by aneroid barometer, with frequent checking on Byford Railway Station and Wongong Siding.

## II. PHYSIOGRAPHY.

### A. *General Relief.*

The area may be considered to be made up of four physiographic units.

1. The partly dissected and eroded block of the uplifted Darling Peneplain (elevation 750 feet to 950 feet). This is mostly covered with laterite above the 800 feet level.

2. The scarp front (elevation 400 feet to 750 feet) which is considerably indented and modified by the drainage system.

3. The subdued "foothill" zone (elevation 250 feet to 400 feet), partly underlain by the Cardup series. This zone is discontinuous and it merges into the fourth unit.

4. The sandy plain (elevation 200 feet to 250 feet) which slopes very gently to the west and forms the eastern border of the Swan Coastal Plain.

This subdivision agrees closely with that given by Woolnough (1918, p. 19), except in the treatment of the foothill zone. Woolnough's Ridge Hill shelf at 200 feet elevation is not represented, except possibly by the small areas of low level laterite near the Beenyup and Cardup Brooks.

### B. *Drainage.*

The Wongong, Beenyup and Cardup Brooks (the main streams in the area, see Plate I) are perennial. Features in common to these streams are:—the westerly direction of flow; the young valleys; the west-north-west trend in the foothill zone.

1. *The Wongong Brook.*—This is the major stream. The U-shaped bend in the Wongong after it enters the area suggests the larger feature observed in the Canning River (Clarke and Williams, 1926, p. 164) and likewise may be a relic of an old north-south drainage channel. This is suggested by the alignment of tributaries with the straight eastern side of the bend and with the early-mature valley of a south-flowing tributary of the Beenyup Brook, a little over a mile to the south. West of this bend, the Wongong flows for a quarter of a mile in a very juvenile valley with walls rising steeply to 500 feet above the stream. Here the tributaries are short, steep and insequent. Downstream the brook swings west-north-west into a broader valley; at the bend, a short channel has been abandoned. The course is gently winding and contains a little alluvium; it receives several tributaries and then passes through the foothill zone onto the plain.

2. *The Beenyup and Cardup Brooks.*—These have young valleys which lack the gorge-like characteristics of the Wongong and possess steeper grades. These differences may be explained by considering the upper portion of the Wongong, east of the area. This can be regarded, like the upper Helena and Canning Rivers, as another example of a consequent south-easterly flowing stream which developed after the uplift of the Darling Peneplain, and was captured and reversed by a more active westward flowing consequent stream (Jutson, 1934, p. 169). Probably the three brooks were developed equally as westward flowing consequents, but the young Wongong, because it had a shorter distance to advance by headward erosion, reached the south-east stream. This led to augmented flow and deepening of the valley. Meanwhile the Beenyup and Cardup Brooks developed tributaries, but retained relatively steep grades.

3. *Minor tributaries to the main stream.*—These comprise:—

   (a) Uncertain relics of a mature north-south system.

   (b) Short steep-graded minor streams which generally enter at right angles to the main stream.

   (c) Larger tributaries which tend to be developed near the scarp; the valleys are youthful, but some broaden in the upper parts. Small waterfalls often occur at an elevation of 400 to 450 feet.

4. *Independent scarp streams.*—These have steep grades and flow west. Examples are the two creeks north of the Byford Brickworks Quarry.

5. *Adjustment of topography to geology.*—Adjustment of the drainage to the major rock structure is not apparent. The courses of the three main brooks form arcs, slightly concave to the north which cut across the strike of the gneiss and the sediments. Two tributaries of the Beenyup Brook appear to have been influenced by quartz blows trending north-west.

Between the Wongong and Beenyup Brooks, streams have deeply embayed the laterite capping by headward erosion, leaving a number of large spurs, some overlying large epidiorite dykes. These spurs represent the most westerly extension of the high level laterite. The sharp edge of the laterite disappears where the mature heads of the creeks approach it and laterite pebbles and sand slope gently up to the laterite level. In such places soaks may develop, the water apparently coming from under the laterite capping.

## III. STRUCTURAL GEOLOGY AND FIELD DISTRIBUTION OF THE ROCKS (see Plate I.).

### A. *Granite and Gneiss.*

1. *Field Occurrence.*—Aplogranite and gneiss are intimately associated, as at Armadale, hence mapping of them separately was not attempted. Also no persistent type corresponding to the fine banded gneiss of Armadale (Prider, 1941) could be found differing in strike from the hybrid gneiss.

Aplogranite tends to outcrop predominantly in the western part of the area. Here near the Wongong the gneissic foliation is usually vague although a few outcrops contain typical hybrid gneiss (Prider, 1941) with basic xenoliths. Farther south from the Rifle Range to the Brickworks Quarry, the gneissic structure is fairly well maintained and basic xenoliths are common. Again in the south-west of the area, between the Cardup and Beenyup Brooks, aplogranite predominates.

The eastern part of the area exposed in the Wongong Brook consists almost entirely of well-banded gneiss which is cut in places by aplite veins. Xenoliths are rare or absent, although biotitic clots and streaks in the gneiss appear to correspond to the basic xenoliths found elsewhere in the area and at Armadale (Prider, 1941).

2. *Structure of the granite gneiss area and the occurrence of Quartz Veins.*—Dips and strikes of the gneiss foliation were mapped, with the knowledge derived from Armadale that the readings in the hybrid gneiss may be unreliable for detailed interpretation. Such local reversals of dip and overturned structures as observed at Armadale by Prider (1941) were found in the western part of the granite gneiss area, but as mapping progressed it was seen that order was maintained in the strike and in a more general way in the dip of the gneiss throughout the entire area. The gneiss in the western part within half a mile of its contact with the Cardup series strikes north-west to north-north-west, hence the contact instead of being parallel to the strike of the gneiss foliation as at Armadale, truncates it obliquely. The series of quartz blows which outcrops "en echelon" across the Beenyup Brook in a north-westerly direction, appears to be related to the structure of the gneiss in the western strip. For three miles north of these blows the general dip is east. South of the blows the gneiss dips steeply to the west. All this evidence indicates that the structure of the gneiss in the western strips bears no relation to the structure of the Cardup series. The gneiss appears to form a major anticlinal structure, cored by quartz blows (steep dip inferred), which may have formed in either a sheared zone or in tension openings along the crest. This anticlinal interpretation is supported by the majority of the dragfolds which also suggest that the anticline pitches gently to the north-north-west.

The gneiss in the eastern part of the Wongong Brook area dips without exception to the west. Dragfolds are rare and they indicate an east limb of a normal syncline. No structural break has been observed between this gneiss and that to the west. On the south side of the Wongong Brook at one point near the broad laterite spur, the foliation is flat-lying, which suggests that the axis of the syncline passes beneath the spur. North of Wongong Brook the strike of the east limb swings north-north-east possibly because of cross-folding. The synclinal structure may extend to Armadale, the axis of the syncline lying east of the area examined by Prider.

The southern extension of this structure is unknown, although it is significant that four miles south, on the north bank of the Cardup Brook the gneiss foliation strikes north-north-east and dips west.

South of Wongong Brook there is considerable reversal of dip on the west limb of the syncline. These westerly dips may be due to either to dragfolding (as illustrated in Plate 2, Section A-B) or to intrusions of aplogranite. The interpretation of this structure as a syncline is confirmed in the distribution of the quartz veins. The N.W. trending veins are the best developed in the area and are most abundant in the vicinity of the Beenyup Brook at the crest of the anticlinal structure. The absence of such large quartz veins in the Wongong valley may be explained by the general synclinal structure of that part of the area.

The "blows" outcrop "en echelon" and do not pass through the contact of the granite gneiss and the Cardup series. A similar relationship has been observed in the quartz blows at Armadale (Prider, 1941). The small north-south blow which disappears under the laterite south of Beenyup Brook represents the north-south type which occurs at Armadale. Weathered sericitic bands in the outcrop suggest replacement by quartz in a zone of sheared granite and gneiss.

### B. *Cardup Series.*

The contact of the series with the granite gneiss is nowhere exposed, but it can be fixed within half a chain in many places by means of slate fragments in the soil and outcrops of the basal sandy beds. Outcrops of these sediments are found along the foot of the scarp, except between the Brickworks Quarry and the Rifle Range, where laterite pebbles and sand obscure the geology. From north of the Wongong Brook to the Armadale area the series is either absent or completely obscured. To the south it appears to persist at least as far as Mundijong (Honman, 1912, p. 63).

The strike of the contact is 356° which conforms with the observed strikes of the series near the contact, where the average dip is 50° to 60° to the west. Small outcrops of epidotic quartzite occur at wide intervals along the contact, these outcrops are resistant to weathering and dip steeply west.

At the State Brickworks Quarry the exposed series has the same succession as at Armadale, thus:—

Upper (4) *Epidiorite* (?)—A sill-like body of red weathered rock.

(3) *Banded White Slate.*

(2) *Black Carbonaceous Slate*—Exhibits features indicating upthrust of the series from the west (Prider, 1941). These are: dragfolds pitching north at 45°: small reverse faults dipping steeply west.

Lower (1) *Grits and Sandstone*—In bands up to 18 inches thick (some are baritic) which alternate with *Sandy Shale* over several chains. Graded bedding in the sandy bands indicates that the beds are normal and not over-turned. These beds lie unconformably on the hybrid gneiss.

South of Beenyup Brook the Cardup series is exposed over a wider area. On the Cardup Brook, white slate outcrops half a mile west of the granite gneiss-Cardup series contact.

In the adit of the barite workings near the contact the same succession of beds as occurs at the Brickworks Quarry is found dipping west at 65°. In the Cardup Quarry at least three epidiorite dykes intrude the slates, which appear to dip almost vertically. The bedding of the slates is obscured by closely spaced fracture planes, caused probably by the intrusion of the epidiorite dykes, because 5 chains west of the large dyke on the west side of the Cardup Quarry the dip of the slate returns to the normal 60° west.

The wider exposures of slate in the southern parts of the area may best be explained as a more complete sequence of the Cardup Series which has been protected from erosion by quartz blows and basic dykes. Isoclinal folding may be advanced as an alternative explanation but no evidence of repetition of the black slates or the basal sandy beds has been obtained and dragfolding, which may have yielded some information in this connection, has been obscured by weathering.

The quartz blows interleave the slates and outcrop "en echelon" as north-south ridges. In the section exposed in the Cardup Quarry the blow quartz forms lenses up to 6 feet wide. Other quartz veins occur in the series; these will be described later in the petrography section.

### C. *Basic Intrusives.*

These are epidiorites, the main types are:—

1. Uralitised quartz dolerites.
2. Porphyritic chlorite-albite epidiorite.

All the dykes in the granite gneiss are of uralitised quartz dolerite. In the north of the area the large dykes have a dominant east-west trend, narrower dykes strike north to north-north-west. Hence the dyke pattern in the north corresponds to that of Armadale (Prider, 1941). In the central part of the area the dykes strike mainly north-west. In the south there are very few dykes— the trend of these being north-east.

Dykes intrude the Cardup series at several places at the contact of the series with the granite gneiss. At Cardup several dykes occur completely in the slates and being roughly parallel to their strike, may be sill-like bodies.

The porphyrite chlorite-albite epidiorite (the albite porphyrite of Esson, 1926), is found only as scattered boulders on the north bank of Wongong Brook and to the south of Cardup Brook. This epidiorite outcrops south of the area, at Whitby Falls and Mundijong (Esson, 1926).

No reliable field evidence can be obtained in the Wongong-Cardup area concerning the relationship between this porphyritic epidiorite and the uralitised quartz dolerite.

### D. *Later Rocks.*

The later rocks are:—

(1) *Laterite.*—This forms a capping over most of the area above 800 feet elevation. Laterite boulders and pebbles occur on the lower levels at the foot of the scarp.

(2) *Alluvial deposits.*—These occur along the courses of Wongong and Cardup Brooks. Silt and sand cover much of the plain (sege pae 266) lying west of the scarp.

(3) *Talus slopes.*—These are formed on the steeper sides of the valleys, and are composed of aplogranite, gneiss and dolerite.

## IV. PETROGRAPHY.

### A. *Aplogranites, Gneisses and Associated Basic Xenoliths.*

The basic xenoliths include hybridised varieties of the biotite-hornblende hornfels found at Armadale (Prider, 1941) and hornblende schist xenoliths.

1. *Biotite-hornblende Hornfelses.*—Xenoliths of these rocks are common in the hybrid gneiss. They form rounded masses up to four feet long. In the granitic phases of the gneiss the xenoliths form narrow sheets intercalated "lit-par-lit" with fine-grained granite.

The rocks are dark grey to black in colour, and generally have a fine even-grained hornfelsic texture.

In thin section, clots of decussate greenish biotite are associated with saussuritised plagioclase. Subhedral hornblende may be present with synantectic reaction rims of biotite or chlorite. Quartz is rare as small clear interstitial areas. Apatite prisms and euhedral sphene, as crystals up to 1 mm. long, are characteristic accessories together with pyrite and magnetite and more rarely, pink euhedral zircon up to 0.5 mm. long.

The felspar crystals are crowded with epidote grains and small clinozoisite prisms. Lamellar twinning is common and extinction angles indicate albite-oligoclase.

Biotite varies from a brownish variety with X = pale yellow to colourless ; Y = Z = yellow-brown ; $X < Y = Z$, to a greenish chloritised variety with X = pale green-yellow ; Y = Z = yellow-brown ; $X < Y = Z$.

The hornblende has the pleochroic scheme :—

X = light brown-green ; Y = dark green ; Z = dark bluish-green ; $X < Y \geqslant Z$ ; $Z \wedge c = 17°$.

The xenoliths are distinguished from the hybrid gneiss by the absence of microcline. Apparently, all the potash which was introduced during granitisation, reacted with the hornblende of the xenolith to form biotite instead of crystallizing as microcline.

Table I.

*Analysis of Biotitic Xenolithic Material.*

| | 1. | 2. | 3. |
|---|---|---|---|
| $SiO_2$ ... ... | 44·95 | 40·09 | 66·52 |
| $Al_2O_3$ ... ... | 17·70 | 14·01 | 13·22 |
| $Fe_2O_3$ ... ... | 3·12 | 6·05 | 4·99 |
| FeO ... ... | 11·32 | 14·42 | 3·29 |
| MgO ... ... | 6·08 | 4·34 | 0·58 |
| CaO ... ... | 3·08 | 9·89 | 2·84 |
| $Na_2O$ ... ... | 3·03 | 0·46 | 3·45 |
| $K_2O$ ... ... | 6·38 | 3·78 | 2·95 |
| $H_2O+$ ... ... | 1·41 | 1·97 | 0·50 |
| $H_2O—$ ... ... | 0·12 | 0·07 | Nil. |
| $CO_2$ ... ... | ... | 0·08 | 0·03 |
| $TiO_2$ ... ... | 1·36 | 2·76 | 0·66 |
| $P_2O_5$ ... ... | 0·95 | 1·24 | 0·10 |
| MnO ... ... | 0·14 | 0·38 | 0·15 |
| BaO ... ... | ... | Nil. | 0·53 |
| $FeS_2$ ... ... | ... | 0·77 | 0·07 |
| $Fe_7S_8$ ... ... | ... | 0·02 | Nil. |
| $V_2O_3$ ... ... | ... | 0·03 | 0·04 |
| | 99·64 | 100·36 | 99·92 |

1. Fine-grained biotitic hornfels xenolith, Cardup (Analyst, B. P. Thomson).
2. Hornblende–epidote–biotite–hornfels xenolith, Roads Board Quarry, Armadale (Prider, 1941, p. 36).
3. Hybrid Gneiss, Roads Board Quarry, Armadale (Prider, 1941, p. 36).

Analysis 1. indicates that the Cardup xenolith is rich in iron and potash like the Armadale hornfels, and is likewise the result of the action of potassic solutions on original basic material. A feature of the analysis is the high alumina content.

This hybridisation (which is essentially a granitisation process involving the addition of $K_2O$, $Al_2O_3$ and $SiO_2$ to the original basic xenolith), was effected during an early period of granite intrusion (Prider, 1941).

2. *Hornblende-schist xenoliths.*—These are not widely distributed like the hornfelses. They occur as angular blocks, up to five feet long, which appear to be part of a larger mass which is cut by narrow veins of aplogranite. They are best developed on the south side of the Wongong gorge, but have also been found in gneiss a quarter of a mile south-east of the Brick Works Quarry and on the south side of Cardup Brook.

The hornblende-schists are black, medium to even-grained and have a schistose structure which may not be apparent in the hand specimen, but is obvious in larger masses. When felspar is present a gneissose structure may develop.

The rock is composed mainly of subhedral hornblende crystals, for which—

X = light yellow-brown; Y = dark brown-green; Z = dark blue-green; $X \lesssim Y \ll Z$ and $Z \wedge c = 18°$.

A small amount of biotite occurs either as plates or decussate clots. The biotite has X = yellow; Y = Z = dark brown and (—) 2V small. Quartz forms small clear angular inclusions in the hornblende. Saussuritised plagioclase is found as subhedral crystals in the slightly hybridised types. Accessories are pyrite and magnetite and rare prisms of apatite and epidote.

The relation between these two main types of xenolith is not visible in the field. The biotite-hornblende hornfels xenoliths represent hybridised rocks, probably of original gabbroic composition. The hornblende-schist xenoliths appear to represent amphibolite which has escaped intense hybridisation.

3. *Hybrid Gneiss.*—This rock is identical with the Armadale type. The foliation is well-marked by biotitic clots and streaks. Light-coloured bands contain pale microcline phenocrysts, greenish saussuritised felspar and quartz. The more porphyritic types have augen of microcline which are developed with vitreous quartz in a black biotitic ground-mass.

The dark bands are similar to the associated biotitic xenoliths and are composed of decussate clots of biotite containing euhedral apatite, sphene, and accessory magnetite and pyrite. Euhedral zircons up to 0.4 mm. long, occur rarely.

The leucocratic bands contain plagioclase (albite-oligoclase) as subhedral crystals which are invariably saussuritised and often sericitised. Occasionally, clear irregular areas of oligoclase occur in the cloudy plagioclase. The twin lamellae are continuous in the clear and cloudy areas, but the extinction angles of the lamellae differ. This may be a replacement structure.

Microcline forms large clear crystals, often with a microperthitic structure. "Phantom Twinning" is present in the central parts of some crystals, indicating that some orthoclase is present, partly inverted to microcline (Alling 1923, pp. 283-305.)

4. *Aplogranite.*—This rock type is the same as the Armadale aplogranite. A typical aplogranite is a medium-grained leucocratic rock, containing albitic plagioclase, quartz and microcline. The texture is allotriomorphic granular. The plagioclase is albite-oligoclase, slightly clouded with kaolin and partly spangled with sericite flakes.

Microcline is microperthitic and slightly kaolinised.

Quartz forms clear allotriomorphic crystals with undulose extinction. Blebs of quartz are also common in the microcline, with which they form myrmekitic structures.

Rare chlorite wisps are the only ferromagnesians present.

A characteristic of the aplogranite is the domination of sericitisation over saussuritisation. Otherwise, the plagioclases in the aplogranite and the gneiss show no marked differences: both are albite-oligoclase, although the abundance of epidote and clinozoisite in the plagioclase crystals of the gneiss suggests that in these the original felspar was more calcic.

5. *Pegmatite and Aplite.*—No coarse-textured pegmatite dykes or veins were found, but the gneiss may be locally pegmatitic and contain microcline crystals up to 2 inches long. Whether this pegmatitic phase is derived from the early granite magma that formed the hybrid gneisses or from the latter aplogranite magma, cannot at present be stated.

*Garnet-Muscovite Aplite.*—A vein of this rock 13 inches wide occurs in the gneiss in the extreme east of the area near the Wongong Brook.

The aplite is pale pink in colour and varies in grain from a fine-grained saccharoidal to a more pegmatitic phase with small microcline phenocrysts and muscovite plates up to 12 mm. across.

The texture in thin section is allotriomorphic. The minerals present are fresh albite, unstrained quartz allotriomorphs, perthitic microcline, rare large muscovite flakes and garnets.

The garnets form small pale pink euhedra up to 0.5 mm. diam. Accessories are a little chlorite and epidote.

Somewhat similar garnet aplites occur at Jimperding (Prider, 1934, p. 10) and Malkup (Cole and Gloe, 1940, p. 160), where they are related to granite intrusions of post-gneiss age.

The origin of this garnet-muscovite aplite is not certain, but because of its remarkable freedom from alteration, it is most probably a phase of the aplogranite.

6. *Relation between the Aplogranite and Hybrid Gneiss.*—In the Wongong-Cardup Area no evidence was found of two types of gneiss striking discordantly to each other, as do the fine-banded and hybrid gneisses at Armadale (Prider, 1941).

Prider considers that there are two periods of granite intrusion.

(1) An early period that led to the formation of the hybrid gneiss.

(2) A later period, represented by the aplogranite. In the Wongong-Cardup Area, two periods of granite intrusion are indicated by—

(a) Angular xenoliths of gneiss in aplogranite, best exposed on the south side of the Wongong Brook gorge.

(b) The truncation of gneissic banding by masses of aplogranite.

### B. *Cardup Series.*

The series may be subdivided into

1. Basal sandy beds.
2. Slates.

1. The basal sandy beds comprise sandstone, epidotic quartzite, and interbedded sandy slates.

(a) *Sandstone.*—This may vary considerably in grain size. The coarser types, which can be classed as grits, contain sub-rounded quartz grains up to 15 mm. long. The matrix is often argillaceous and the quartz grains show imperfect graded bedding.

In finer-grained sandstone on the western side of the Brickworks Quarry, ripple-marking appears to be present.

Vughs, which may have originated by the leaching out of calcite, are common in the grits. These vughs are lined with small quartz crystals, and some contain white or colourless barite. At Cardup a small amount of purple fluorite is associated with the barite, a little pyrite and chalcopyrite are also present. White calcite occurs in some unweathered specimens.

In thin section:—

The typical sandstone contains rounded to sub-angular quartz grains interlocking loosely in a ground mass of micro-crystalline quartz and sericite. The quartz shows undulose extinction. Rounded pink zircons occur sparsely, but are rarely absent. In one section several small idioblastic crystals of tourmaline were found.

The baritic sandstone has a granular structure which is obscured by a mosaic of later vein-quartz. Angular cloudy felspar fragments (mostly microcline) are common. Barite forms irregular grains and strings. Calcite and rounded pink zircons are present.

(b) *Epidotic Quartzite.*—This rock has been shown by Prider (1941, p. 40) to be sandstone which has undergone contact metamorphism, due to the intrusion of epidiorite. This is supported south of Wongong Brook, where an outcrop of the quartzite grades into sandstone and is associated with fine-grained epidiorite.

The quartzite varies from a grey-green even-grained rock with a conchoidal fracture to a banded rock in which sandy and cherty bands alternate. Some of the sandy bands show graded bedding. Pyrite and marcasite are present in small amounts.

In thin section clear rounded quartz grains are seen to be rimmed with a plexus of small pale green needles of an optically negative biaxial mineral with oblique extinction (probably actinolite).

The quartz is strained. Epidote is present as small interstitial grains or as yellow-green clots. The felspar forms slightly clouded subhedral crystals, either of microcline or plagioclase.

Small rounded zircons are common.

The cherty bands contain microcrystalline quartz which is streaked with nearly isotropic white material and is spotted with epidote grains.

2. Slates:—

Black and white slates, similar to those found at Armadale, are exposed at the Brickworks Quarry and at Cardup. On the north bank of the Wongong Brook, white and grey sandy slate outcrop, but no black slate is exposed.

(i) *"Black" Slate.*—This is a black to dark-grey coloured rock, in which close bedding planes are well developed and marked by alternating light and dark bands.

Barite occurs on the joint planes of the black slate in the Brickworks Quarry.

In thin section:—Minute sericite plates and microcrystalline quartz form the ground mass which is banded with graphitic material. Light brown-green idioblastic tourmaline prisms are scattered with random orientation throughout the rock.

(ii) *"White" Slate.*—This variety of slate has a white to light grey colour. The light grey type is compact and hard and corresponds to the slate interbedded with the sandstones. Such slate shows a greater development of microcrystalline quartz, under the microscope, than do the lighter types.

In thin section the white slate is seen to consist of minute sericite flakes and a smaller amount of microcrystalline quartz, which may be intermixed with or may form lenticles in the sericitic groundmass. Later veinlets of strained quartz cut the bedding.

In the Cardup quarry, pale green chlorite is developed in the "white" slate near the contact with an epidiorite dyke.

The small tourmaline prisms are distributed sparsely throughout all the slates, and do not decrease in quantity, even half a mile west of the Cardup Series-granite gneiss contact at Cardup. This supports Prider's suggestion (1941, p. 41) that the tourmaline was derived from the crystallisation of the original constituents of the argillaceous sediments rather than from material introduced by an intrusive granite.

### C. *Basic Intrusives of Post-Cardup Age.*

The following types are recognised:—

1. *Uralitised quartz dolerite.*
2. *Biotitic epidiorite.*
3. *Porphyritic chlorite-albite epidiorite.*

1. *Uralitised quartz dolerite.*—As at Armadale, most of the dykes are of this dominant type.

A typical specimen is dark grey-green in colour, with fine to medium grain. The texture is ophitic to subophitic and is obscured by the formation of uralite and epidote.

Uralitic amphibole is the dominant mineral. Plagioclase occurs, almost entirely replaced by granular epidote and zoisite.

The mesostasis is clear quartz, often in micrographic and rarely granophyric intergrowth with the epidotised felspar. The quartz encloses apatite prisms. Brownish hornblende, biotite and chlorite may be associated with the uralite. Leucoxene is abundant as large skeletal plates replacing ilmenite. Some leucoxene has also recrystallised to granular sphene.

The uralite is often developed in large crystals with good cleavage and simple twinning. The colour is rather variable in intensity, a typical pleochroism is X = very pale yellow-green ; Y = pale olive-green ; Z = pale greenish-blue ; $X < Y \ll Z$, $Z \wedge c = 20^\circ$, (−) 2V is large.

Closely related to the ordinary uralitised quartz dolerite is the variety in which the felspar is tinted by pale-brown smoky clouding. Only one dyke has been found to contain felspar in this condition. None have been found at Armadale, but they occur farther north at Gosnells, Lower Chittering and Malkup.

According to MacGregor (1931), such features are due to reheating of the rock after consolidation.

The felspar varies from fresh labradorite, with the characteristic brown tint, to intensely saussuritised felspar and is in ophitic relation to the uralite plates.

The uralite develops blue-green resorption borders in contact with the felspar and in places appears to grade into brownish hornblende.

Unstrained quartz forms a mesostasis and skeletal ilmenite, rimmed with leucoxene, is common.

*Associated Veinlets.*—In the uralitised quartz dolerite, veinlets of epidote or quartz are found up to two inches wide.

2. *Biotitic epidiorite.*—This Armadale type has been found only near the prospecting shaft, north of Wongong Brook.

Its field relations are not known: it probably represents a phase of the uralitised quartz dolerite.

Megascopically it resembles a hornfels, being black and fine-grained.

The thin section reveals an allotriomorphic granular aggregate of greenish-brown biotite, small plagioclase laths (which are almost completely converted to epidote), uralite, leucoxene, quartz and sparse pyrite.

The biotite has the pleochroic scheme:—

$X =$ pale yellow-green; $Y = Z =$ brown-green $X < Y = Z$.

Uralite forms sparse patches with biotite which is apparently derived from it.

3. *Porphyritic chlorite-albite epidiorite.*—Mineralogically, this rock corresponds to the albite epidiorite of Armadale (Prider, 1941).

Hand specimens show yellow subhedral albite phenocrysts (up to 3 cm. long), in a dark fine-grained ground mass. In the Cardup specimens the phenocrysts are grouped radially, forming "rosettes" up to 5 cm. in diameter.

In thin section, albite phenocrysts are set in a ground mass of albite laths, uralite, biotite and chlorite with a little interstitial quartz and leucoxene.

The albite is cloudy and contains epidote. The phenocrysts are rimmed and penetrated by the chloritic ground mass.

Uralite is rare and is a soda-rich variety with $X < Y \ll Z$, $X =$ pale yellow; $Y =$ pale olive-green; $Z =$ bright green-blue, $Z \wedge c = 17°$.

In the ground mass are found aggregates of deep-green chlorite or decussate brown biotite, each containing several euhedral epidote crystals.

### D. *Quartz Veins and Barite.*

The quartz veins may be subdivided into—

1. Quartz veins in the granite gneiss.
2. Quartz veins in the Cardup Series.

1. Quartz veins in the granite gneiss. There are two types:—

(a) The small north-south striking vein south of Beenyup Brook. The vein averages five feet in width and is identical with the corresponding type of "blow" at Armadale. It contains sericitic bands, and in thin section shows cataclastic structures and recrystallised sericite. This suggests a replacement by quartz along a shear zone.

(b) The north-west striking blows, which cross the Beenyup Brook. These are, on the average, 4 feet wide and may be traced continuously for distances up to 10 chains or more. No sericite bands are observed in these. Fresh specimens of the quartz are greenish-grey, massive and frequently contain later quartz veinlets and pyrite. On joint surfaces which have been bleached by weathering, angular fragments of quartz up to 4 inches long are seen to be set in a fine-grained cherty matrix. Thin veinlets of later quartz traverse both the fragments and the matrix.

The quartz in the angular fragments shows strain and cataclastic structures. A small amount of felspar is present. The crystals are probably of microcline, they are allotriomorphic and slightly rounded.

The ground mass is fine grained quartz, through which, in the unweathered rock, shreds of chlorite and biotite are distributed.

This evidence suggests that these blows are not simple replacement bodies formed along shear zones. They may represent quartz reefs, which after their formation, have been sheared and then partly replaced by later quartz.

2. Quartz veins in the Cardup Series. These are:—

(a) Quartz Blows in the slates at Cardup.

There appears to be two parallel series of quartz blows, striking north and south in the slates at Cardup:—

(i) The westerly series which is the more strongly developed. These average 5 feet in width and outcrop continuously for distances of more than 10 chains. A section of one of the blows of this series is to be seen in the east wall of the main Cardup quarry and it appears to be made up of bulbous quartz lenses up to 4 feet wide, dipping at 85° to the west. These lenses appear to conform (in strike and dip) to the slate which has been distorted, so that the bedding now follows around the edge of the quartz lenses.

(ii) The easterly series which outcrops in a north striking zone some 5 or 6 chains to the east of (i). These veins are lenticular and the lenses are more elongated than in (i). They conform to the dip and strike of the slate.

Under the microscope, the quartz in (i) and (ii) is practically identical as regards intensity of shearing. Weathered outcrops may be massive or show a pseudo gneissic structure caused by fine ferruginous streaks. This structure is cut by later quartz veinlets, up to one inch wide, in which vughs occur.

The quartz is intensely sheared and large crystals (including those of later veinlets) show slicing and granulation.

Thin shreds of greenish pleochroic chlorite (?) are arranged parallel to the lines of granulation. Twisted plates of muscovite occur sparsely and iron ore in subhedral grains is common.

(b) "Contact" Quartz Veins. These occur at several places on the granite-gneiss-Cardup Series contact. One is well developed south of the Brickworks Quarry and it closely resembles the north-south type of blow of Armadale. It contains sericite bands and the quartz shows cataclastic structures.

(c) Vein quartz in the baritic sandstone. "The quartz-barite vein" (Clarke, 1930, p. 166) at Cardup is sandstone which is veined and partly replaced by later quartz and barite.

In thin section the veinlets are seen to consist of clear quartz forming a mozaic of slightly strained crystals.

(d) Narrow veins of vitreous quartz, up to one inch wide, occur in the black slate of the Brickworks Quarry. The quartz is limpid and shows undulose extinction.

3. *Origin of the quartz veins in the Cardup Series*:—In the light of other evidence, indicating that the Cardup Series is post granite in age, it is suggested that these veins are the result of a period of vein formation that followed the intrusion of the epidiorite. The veins are possibly the result of differentiation of the basic magma.

Coulson (1933, p. 114) suggests such an origin for the quartz reefs associated with certain Indian barite deposits. Although the age relationship between the epidiorite and quartz veins in the Cardup Series has not been determined in the Wongong-Cardup area, post-epidiorite quartz veins are known to occur at localities near the area.

Prider (1941, p. 42) mentions that at Armadale, in the tunnel west of the slate quarry, vein-like bodies of quartz that show pronounced cataclastic structures occur in uralitised quartz dolerite.

Esson (1926, p. 7) states that quartz reefs of the silver lead deposits at Mundijong occur in the epidiorites which intrude the slate of the Cardup Series.

4. *Origin of the barite.*—The minerals associated with the barite in the sandstone are quartz, pyrite, chalcopyrite, calcite, and purple fluorite. These minerals, except possibly the calcite, appear to be the result of one period of mineralisation.

Because of the irregular distribution and the absence of banded veins, the paragenesis cannot be worked out. Nevertheless, such an association of minerals indicates a hydrothermal origin for the barite (Laurence, 1939, pp. 190-200).

Prider (1941) suggested that the silver-lead bearing veins of Mundijong and the barite and fluorite are both related to the albite epidiorite magma. Coulson (1933, p. 115) considers that the barite of certain Indian deposits are derived from a somewhat similar basic magma.

Whatever their source, the hot barytic solutions appear to have ascended into the porous basal sandy beds of the Cardup Series in many places. Solutions containing barium ions have also migrated along the fracture planes of the slates, where barite has been deposited (p. 275).

## E. *Later Rocks.*

1. *Laterite.*—The distribution of this rock has been described (p. 270).

The high level laterite is the common pisolitic variety, and it does not appear to vary markedly in composition, whether developed over epidiorite dykes or granite gneiss.

On the slopes below the laterite, fragments of a dark-red fine-grained limonite rock are found in a few restricted areas. Thin section reveals a fine-grained matrix of limonite with a small amount of interstitial quartz. This rock may be equivalent to the ferruginous grit found below the laterite of other Darling Range areas (Miles, 1938, p. 32).

On the lower levels laterite occurs as boulders of the pisolitic variety or as unconsolidated deposits of limonite pebbles with sand or ferruginous clay.

2. *Alluvium.*—The alluvium in the Wongong Brook is sandy. At the bend west of the gorge, large boulders of conglomeratic rock lie in the abandoned stream bed. This rock contains pebbles and boulders of granite and gneiss which have been cemented by clay, in the banks of the stream.

## V. CONCLUSIONS.

### A. *Age of the Cardup Series and its relation to the granitic rocks.*

The structure of the gneiss can be broadly interpreted as due to folding which took place before the formation of the Cardup Series. Further facts similar to those recorded by Prider (1941) support the conclusion that the gneiss and granite are older than the Cardup Series. They are:—

(i) No quartz or pegmatite veins have been observed to pass from the granite and gneiss into the Cardup Series.

(ii) The Cardup Series maintains a normal erosion sequence and the basal beds must rest upon the eroded granite gneisses which strike obliquely to the Cardup Series.

(iii) Xenoliths of the sediments are absent from the gneiss.

(iv) The gneiss does not vary in character across the strike and therefore does not appear to be a granitised phase of the Cardup Series.

(v) Contact metamorphic effects in the sediments are slight and are due to basic intrusions.

(vi) The widespread occurrence of small idioblastic crystals of tourmaline in the slates can be readily attributed to original boron in the sediments rather than to pneumatolytic effects of a granite intrusion.

(vii) Rounded zircons are found in the basal sandy beds of the sediments, whereas mineralogically similar zircons occurring in the gneiss and basic xenoliths are unrounded. This points to the possible derivation of the Cardup Series (in part at least) from the gneiss.

(viii) Detrital microcline, most reasonably regarded as derived from the aplogranites and gneisses, occurs in the Cardup sediments.

### B. *Darling Scarp.*

Prider, (1941), considered that the Darling Scarp was produced by the differential erosion of a monoclinal fold, and was not primarily a fault structure as has been suggested by most geologists (Jutson, 1934, p. 87). He based his conclusions on the minor structures in the slates at Armadale, which indicate an upthrust from the west, the result of a downwarp of sediments to the west of the area. In the Wongong-Cardup area, similar structures are found in the slates of the State Brickworks Quarry. It is true that at Cardup, slate further west of the granite gneiss Cardup Series contact dips almost vertically which is hard to reconcile with the upthrust, but this steepening of dip may be attributed to the deformation produced by the nearby basic dykes.

The "foothill zone" (p. 266), which is partly underlain by the Cardup Series, can be attributed to the effect of differential erosion between the sediments and the granite gneiss.

### C. *Comparison of the Wongong-Cardup, Armadale and Gosnells Areas.**

All three areas are situated on the Darling Scarp, on an igneous metamorphic complex, flanked on the west by the Cardup sedimentary series which strikes almost due north and dips steeply to the west.

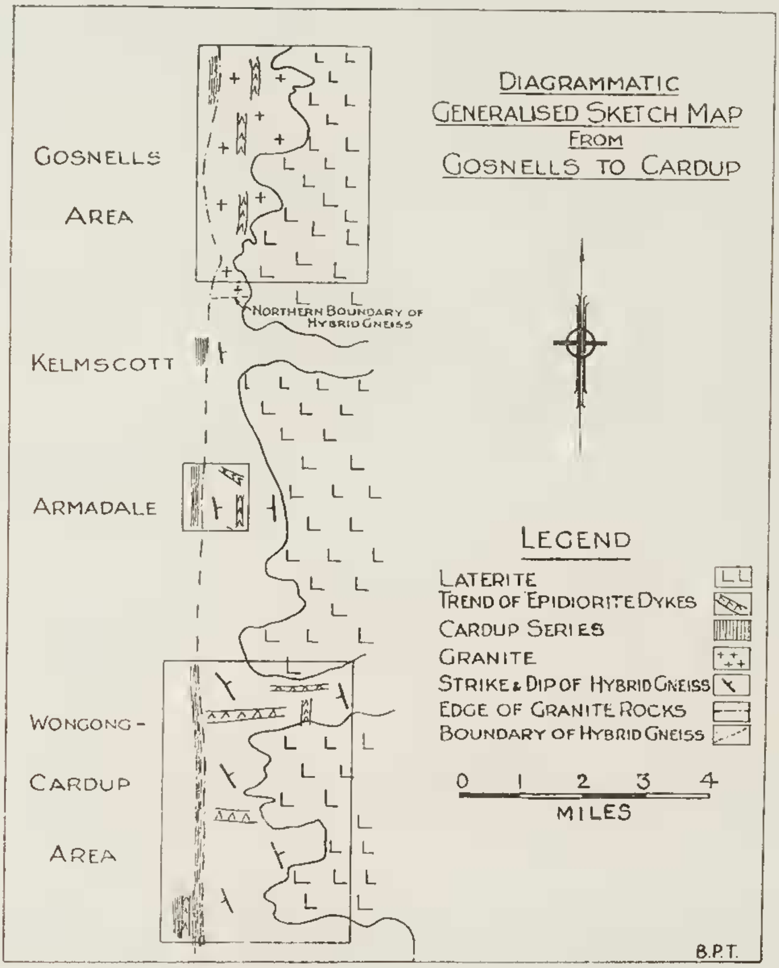

Fig. 1.

There are as yet insufficient data to give a complete structural picture of the igneous-metamorphic complex. The known facts from the three areas examined (which are illustrated in fig. 1) are:—

(1) The predominant rock in the areas examined is a hybridised gneiss which is best developed in the Wongong-Cardup and Armadale areas. In the Wongong-Cardup area the gneiss is considerably folded and the strike varies from N.W. to N.N.E. while in the Armadale area the general strike is almost due north. At Gosnells the granitic rocks are generally massive without any gneissic structures. Post-gneiss massive granites occur at both Armadale and Wongong-Cardup where they form only a minor part of the complex—these granitic rocks (aplogranites) may possibly be offshoots from the main Darling Range massive granite which lies to the north of Gosnells.

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*This section was written in collaboration with Dr. R. T. Prider and Mr. C. E. S Davis.

(2) Quartz veins are developed in all three areas, the trend being N.N.W. at Cardup, W.N.W. at Armadale, and N.E. at Gosnells. In none of the areas have quartz veins been observed to pass from the granitic rocks into the Cardup Series (although many were traced to the boundary between these two formations) and this is the main evidence for regarding the granitic gneiss complex as pre-Cardup in age. Quartz veins occur in the slates at Cardup but these are of a different type and probably genetically related to the younger basic intrusives.

(3) Basic dykes are common to all three areas but a marked variation in trend is noticeable. In the Wongong-Cardup area and at Armadale the general trend is E.-W. with a few N.-S. dykes whereas at Gosnells the general trend is in a N.-S. direction. The basic intrusions are all of post-Cardup age.

The Cardup Series is developed in all three areas and the succession, lithology, grade of metamorphism and relation of the Series to the granitic rocks and to the later basic intrusives are similar throughout .

Post-Cardup basic intrusives belong to two main types, (i) albite epidiorite and (ii) uralitised quartz dolerites, both of which are developed in all three areas. They have been assigned to two ages—the earlier albite epidiorites having accommodated themselves to the earth movements affecting the Cardup Series, while the later quartz dolerites have been comparatively little altered.

Although the significance of the various structural patterns of these three areas (as seen in the general trend of the gneissic structures, quartz veins and basic dykes) is not as yet completely understood, it is the authors' opinion that the Darling Range complex consists of an older hybridised granitic gneiss intruded by a later batholithic granite extending over the area between Gosnells (on the south) and Lower Chittering (on the north). Offshoots (aplogranite) from this granite mass have penetrated the older hybridised gneisses lying to the south of Gosnells. The Cardup sedimentary Series is definitely of later age than the granitic rocks and the various basic intrusions are younger still.

## VI. GEOLOGICAL HISTORY OF THE AREA.

(1) Period of granitisation, during which the hybrid gneisses were formed from older basic rocks.

(2) Folding of the hybrid gneiss (by pressures directed from the N.N.W. and S.S.E.), probably closely followed by, or contemporaneous with, (3).

(3) Aplogranite intrusions.

(4) Earth movements, forming shear zones and joints in the gneiss, followed by the formation of quartz veins, which may represent the end-phase of the aplogranite magma.

(5) Erosion of the granite and gneiss and deposition of the Cardup Series.

(6) Downwarp to the west of the area, causing upthrust of the Cardup Series towards the east over the granite gneiss.

(7) Intrusion of the epidiorites.

(8) Formation of post-Cardup quartz veins and the introduction of barytic solutions. Both of these are the end-phases of the epidiorites.

End of the Pre-Cambrian.

(9) Deposition of sediments west of the area, leading to further downwarping which may have produced strain effects in the quartz veins in the slates.

(10) Continued erosion leading to peneplanation and laterite formation (Woolnough, 1918, p. 385).

(11) Uplift of the peneplain in late Miocene times (Jutson, 1934, page 205). and probable formation of the Darling Fault.

(12) Further erosion, producing the present topography.

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